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The Tenth Grove Fuel Cell Symposium

FUEL CELLS IN A CHANGING WORLD – A PROGRESS REPORT

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The Grove Fuel Cell Symposium and exhibition was again held at the Queen Elizabeth II Conference Centre in Westminster, London, on the 25th to 27th September 2007 (1). The conference, the tenth in the series over 18 years (2), attracted 375 delegates from 32 countries. While the conference remains the largest fuel cell gathering in Europe, attendance was slightly less than in 2005, which may have reflected the scheduling of the 2007 Fuel Cell Seminar & Exposition, held only a fortnight later in San Antonio, Texas, and 'f-cell 2007', almost simultaneously on 24th to 25th September at Stuttgart, Germany. A further 800 people attended the trade exhibition held in parallel with the Symposium. This exhibition was remarkable for the proportion of working exhibits and vehicles – a sign of the considerable progress being made towards commercialisation by the fuel cell industry. A large number of fuel cell types have been developed to the semi-commercial demonstration stage, and in several cases production is ramping up, which will bring about the long awaited cost reductions to make fuel cells economically competitive.

Because of the wide range of fuel cell types and applications being developed, and in line with the coverage of this Journal, this review is mainly restricted to those associated with the use of the platinum group metals (pgms).

A fuel cell powered Micro Taxi built by Coventry University, U.K.

Grove Medal Presentation

The event was formally opened by Bronwen Northmore (Head of Cleaner Fossil Fuels at the U.K. Department for Business, Enterprise and Regulatory Reform), on behalf of Malcolm Wicks, the U.K. Energy Minister, who was attending the Labour Party Conference. The U.K. Government strategy, initiated by the Climate Change Bill, is intended to encourage energy savings and support low carbon technologies. This has led to the establishment of an Energy Technology Institute which will investigate distributed energy generation and low carbon transport, together with a technology demonstration programme.

Bronwen Northmore presented the Grove Medal to Haldor Topsøe, founder of Haldor Topsøe A/S of Denmark. The medal was accepted on his behalf by Professor Jens Rostrup-Nielsen, since Haldor Topsøe was unavoidably detained on business. At the age of 94, Haldor Topsøe is still actively engaged in running the company and hence his talk was also presented by Professor Rostrup-Nielsen, who explained that he created the vision and pushed people to have ambitions in their work. Haldor Topsøe A/S was set up to develop chemical processing plant, concentrating on catalysis and materials technology, and has built several types of hydrogen production system. The Topsøe philosophy is to anchor their business on a fundamental understanding of the processes involved, which has involved fundamental research as well as exploitation of this work.

Topsoe Fuel Cell has been collaborating with the Risø National Laboratory in Denmark to develop solid oxide fuel cells, on the understanding that the final products must compete in cost terms. Performance of the fuel cells has been successfully demonstrated, but so far they have not been cost-competitive. Steps are being taken to eliminate scrap in manufacture, and to reduce the number of unit operations in production. A factory is being built in Lyngby, Denmark, with a capacity of 10 MW $year^{-1}$, which is due to begin production in 2008. The development is expected to take 8 to 10 years, which is similar to the timescales for other chemical processes developed by Topsøe. Despite his age, Haldor Topsøe takes a long-term view, as typified by his current reorganisation of the company structure, and the belief that fuel cells must compete economically with other technologies, while providing other benefits such as fuel flexibility and efficiency.

Challenges and Solutions

In the first Plenary Session, in a talk entitled 'Environment and Energy Challenges', Professor Jim Skea (UK Energy Research Centre) outlined the challenges presented by global warming, and the increasing demand for energy due to increasing affluence worldwide. A further factor is becoming important for the European Union – security of supply. Between now and 2030, there will be a 50% increase in oil demand, most of which will continue to be met from the Middle East, while by 2030, 80% of natural gas will come from sources outside the European Union. The United Kingdom became a net oil importer in 2006, due to a run-down of North Sea Gas supplies. Professor Skea outlined the choices available to minimise global warming. He concluded that the need to do this is pressing, but that the means to meet the need are available if mankind takes up this huge challenge.

Jan van Dokkum (UTC Power, U.S.A.) acknowledged that the United States is at last recognising the existence of climate change. As well as population increases, an additional factor to be addressed is that people are increasingly living in cities. Urban dwellers use more energy, and are dependent on secure power supplies. Between 1970 and 2030, the proportion of urban dwellers is expected to increase from 35% to 60% worldwide. Capitalising on almost 50 years of experience gained in the space programme and other fuel cell developments, United Technologies Corporation has for the past 15 years produced a 400 kW phosphoric acid fuel cell (PAFC) system, which has now demonstrated 10 year lifetimes for the cell stack. Stacks are guaranteed for 5 years (44,000 hours) and currently last 50,000 to 70,000 hours. UTC are continuing to develop PAFCs, with a target to double power output and lifetimes while halving cost as compared with early cells, with a view to producing an economically viable stationary power system.

UTC is also developing polymer electrolyte membrane (PEM) fuel cells for buses. This application avoids many of the near-term barriers to automotive applications such as power density, cost and refuelling. Buses with UTC Power fuel cell systems are in revenue service, and their centralised refuelling facility is contributing to the development of a hydrogen supply infrastructure which will benefit other automotive applications. In general, government support is needed on aspects such as codes and standards, to facilitate installation of fuel cells, and incentives to encourage more efficient use of energy. To date, fewer than 1000 fuel cell vehicles have been produced, so it is hardly surprising that costs currently compare unfavourably with those of internal combustion engine (ICE) vehicles, tens of millions of which are built each year (3). However, UTC is of the opinion that the cost target of U.S.\$45 kW^{-1} set by the U.S. Department of Energy for automotive fuel cell power plants in 2010 (U.S.\$30 in 2015) is achievable with mass production (4). The cost of hybrid ICE/electric vehicles is rapidly decreasing, and fuel cell vehicles are inherently simpler than these. One of the main barriers to the adoption of automotive fuel cells is the need for a hydrogen refuelling infrastructure.

Michael Bode (CFC Solutions GmbH, Germany) outlined progress being made in stationary power generation. His company has developed molten carbonate fuel cells, which are built up in 220 kW modules and demonstrated worldwide in 40 installations ranging from 200 kW to 2000 kW rating, operating on a range of fuels including renewable energy sources. Bode outlined the challenges that have been addressed to improve reliability and cost, and to commercialise the system.

Road Vehicles

Although progressing more slowly than predicted some years ago, light passenger fuel cell vehicles are being developed by most of the major automotive producers worldwide. James Wilkie (ACAL Energy Ltd., U.K.) argued that the current popularity of internal combustion engine/hybrid electric vehicles (ICE/HEVs) provides a valuable learning experience for fully electric models. Increasingly stringent pollution legislation is making it more expensive for ICEs to meet the requirements, while the mass production of hybrid petrol/electric and diesel/electric vehicles is bringing down the costs of compliance. Over 1 million HEVs have been produced to date, compared with the small number of prototype fuel cell vehicles worldwide. Sales of the Toyota Prius and other hybrid models alone amount to 400,000 to 500,000 vehicles worldwide per year. This is still small compared to the 57 million ICE vehicles produced, but it is sufficient to bring down production costs, and the perceived environmental friendliness of hybrid vehicles has been of enormous brand value to the manufacturers. Regarding complexity, the fuel cell vehicle has only one power source, and will benefit from developments for HEVs in batteries, motors and features such as regenerative braking and lightweight body design. Familiarity with electric drive systems will facilitate consumer acceptance of fuel cell models. Automotive fuel cells still face challenges in terms of hydrogen storage on board, and stack costs and availability, as well as development of a chain of publicly available hydrogen filling stations. Wilkie suggested that technology such as the through-flow cathodes being developed by ACAL Energy Ltd. in combination with aqueous redox mediator systems could reduce the need for pgm catalysts as well as facilitate the cooling of the fuel cell stack.

Zoe Jennings, Daniel Pizarro and Mike Weston (London Hydrogen Partnership, U.K.) revealed plans for a collaboration by Transport for London, the Metropolitan Police, the London Fire Brigade and other organisations to run trials on 10 buses and 60 light vehicles. Nine European cities, including London, were involved in the Clean Urban Transport for Europe (CUTE) bus programme which has now been completed, and this will be followed by operating a whole city bus route from the summer of 2009 for 18 hours a day, 365 days a year.

Large Stationary Applications

PAFCs catalysed by platinum are being advocated for a range of applications where waste hydrogen is available. Leo Blomen explained how HydroGen Corporation, U.S.A., has been set up with private finance to exploit the air-cooled technology originally developed by Westinghouse in a \$150 million programme which is being revived and adapted. The company will focus on a small number of very large customers, with a fuel cell unit rating likely to be 5 to 30 MW, comprising multiples of modules each of 400 kW output. The first two 400 kW modules have already been produced. There are numerous hydrogen waste streams originating from sources such as chloralkali and chlorate plants, coke oven gases, ethylene off gas, ammonia and methanol production plants. These are often located at sites near harbours such as Houston-Galveston, Rotterdam, Shanghai and Long Beach, and the hydrogen-rich byproducts are frequently vented. This waste hydrogen can be used to provide heat, water and electric power, as well as financial credits and incentives.

A measure of the durability of the PAFCs is provided by the observation that a 15 year old 400 kW fuel cell module built by Westinghouse has been taken out of store, refilled with phosphoric acid and restarted, the open circuit voltage being within 1% of the original. HydroGen opened a factory in Versailles, Pennsylvania, in 2006 with an annual production capacity of 4 MW, which is intended to ramp up to 100 MW $year^{-1}$ by 2010. Their first installation will be a 400 kW demonstration unit at Ashtabula, Ohio, in a commercial chloralkali plant operated by ASHTA Chemicals Inc.

A similar application was reported by Eric Middelman (NedStack fuel cell technology BV, The Netherlands), using PEM fuel cells to recover energy from waste hydrogen originating in chlor-alkali plants. NedStack was formed in 1998 to use technology developed by Akzo Nobel, and is the largest European producer of fuel cells. The technology uses thin moulded thermoplastic separator plates with microchannel flow fields, which have demonstrated over 200,000 hours of operation without deterioration. The company also produces fuel cells for other stationary and transport applications, 98% of which are exported. The chlorine and chlorate industries often produce waste hydrogen equivalent to 25 MW capacity from a single plant, while hydrogen overcapacity in the U.S.A. amounts to over 3000 MW. The NedStack fuel cell modules each produce 50 kW (80 A at 630 V) DC power, while the system delivers 380 to 400 V AC power back to the grid. NedStack have demonstrated a 120 kW plant operating at Chemiepark Delfzijl, The Netherlands, as part of a petrochemical production complex, where it meets normal industry safety standards. Durability required for industrial production plants is in excess of 175,000 hours for the whole system, and at least 40,000 hours for the fuel cell stacks. Rates of voltage decay of less than 1.8 μV hour^{-1} have been observed (i.e. less than 10% voltage loss in 40,000 hours), while the best

NedStack 50 kW fuel cell module, used in the demonstration project at Chemiepark Delfzijl, The Netherlands (Courtesy of NedStack)

stacks have given 0.1 μV hour^{-1}. Typical behaviour observed in production stacks is a more rapid decay in the first 400 hours, which then stabilises at less than 0.2 μV hour^{-1}.

Significantly, NedStack state that while their PEM fuel cells are heavy duty models designed to be robust for the chemical industry, the cost of platinum they contain is less than 60 € kW^{-1} without recycling, or less than 3 € kW^{-1} with recycled metal. Due to the use of otherwise waste hydrogen, the payback on the system is less than 3 years, although the economic feasibility will obviously depend on factors such as the competing cost of power from the grid, hydrogen purity, local funding and support. Cost of the system is currently 700 to 1500 € kW^{-1}, which is scheduled to be reduced to 75 to 250 € kW^{-1} by 2010. At 250 € kW^{-1} the system is directly competitive with diesel engines. Overall, the project is well on schedule to meet durability, safety and economic targets.

Transport Applications

Papers were presented on several novel applications for PEM fuel cells. Paul Adcock (Intelligent Energy, U.K.) described his company's range of fuel cells, some of which are intended for passenger automotive power. Their model EC200-192, which has a stack active area of 200 cm^2, and 192 cells, can provide a maximum of 17 kW at 90 A. This has demonstrated a lifetime of over 5000 hours, with an average voltage decay rate of 3.2 μV hour^{-1} in a 23 hour operating day with 1 hour shutdown. The metallic bipolar separator plates offer the advantages of compactness with low voltage loss characteristics.

A 10 kW fuel cell engine intended for the Peugeot Partner light van has an efficiency of 47%, and is capable of starting from –25ºC. It can provide 80 A after 60 seconds and is almost self-heating. The company is also developing a 75 kW high-power PEM fuel cell in collaboration with PSA Peugeot Citroën/Bosch, which is capable of starting from –40ºC. The fuel cells are all designed to operate on industrial grade hydrogen of 99.99% purity, and ambient air. Although the fuel cells are still only available in limited quantities, the eventual costs should meet the U.S. Department of

Energy target for automotive fuel cells, once mass production levels are achieved.

John Heinzel (U.S. Department of the Navy, Naval Sea Systems Command (NAVSEA)) detailed the range of fuel cells being investigated by the United States Navy. One of the constraints on any military fuel cell is the need to be capable of operation on the high-sulfur logistics fuels generally used. Other requirements are high reliability and resistance to vibration and electromagnetic pulses, as well as to possible salt contamination of the inlet air. Heavy marine fuel can contain up to 1.5% by weight of sulfur, while JP5 jet fuel contains up to 0.3 ppm by weight. The U.S. Navy is evaluating various fuel cell technologies, including a 625 kW solid oxide fuel cell, operating on sulfur contaminated fuel, and a 500 kW PEM fuel cell system. A 50 kW PEM fuel cell is being used together with a 250 kW autothermal reformer to demonstrate operation on fuel containing up to 1000 ppm sulfur. Eventually power generator units of 2500 kW rating are being considered, consisting of 5 × 500 kW fuel cell modules, in cabinets occupying a volume of 7.31 m × 2.44 m × 2.44 m. Small units are expected to be available during the next 2 years, while 250 kW units are expected to be available in the 2012 to 2015 timeframe. The fuel cell stacks are required to have a 10,000 hours minimum lifetime, even when exposed to salt air; vibration and mechanical shock are still issues.

The marine market for fuel cells is potentially very large, with 87,000 commercial vessels at sea. The majority have relatively small propulsion units, rated at less than 2 MW, which are built at the rate of over 5000 $year^{-1}$. There are also more than 10,000 vessels in the small to midsize range (up to 10 MW). Marine diesel engines produce around 4.5% of the NOx emissions and 1% of the particulates from all mobile sources. These emissions are a particularly sensitive issue when the vessels are in port, and for this reason the Environmental Protection Agency (EPA) and California Air Resources Board (CARB) are considering regulations for engine cleanliness.

Nina Lapeña Rey (Boeing Research and Technology Europe, Spain) gave details of a project called the Fuel Cell Demonstrator Airplane, intended to demonstrate for the first time an aircraft propelled in straight level manned flight with fuel cells as the sole energy source. A Super Dimona HK36TTC glider from Diamond Aircraft Industries in Austria has been modified to accept a PEM fuel cell system provided by Intelligent Energy, in combination with a 25 kWe lithium-ion battery from SAFT Aviation. The fuel cells can provide a gross output of 18 kW from each of two EC168 stacks, and the battery has been sized to provide up to 50 kW power for 5 minutes for safety purposes. The aircraft is intended to use both power sources for the 7 minutes required for takeoff and the climb to 1000 feet (305 m), after which the fuel cell will provide 18 kW to maintain the cruising speed. Fuel will be provided by a hydrogen store at 5000 psi, and the weight distribution of the components has been arranged to maintain the correct centre of gravity of the aircraft. The airplane is currently undergoing bench testing to thoroughly check the performance and reliability of all components and overall systems prior to ground and flight tests. It is hoped to begin these in late 2007.

In a talk entitled 'Near Term Fuel Cell Locomotives for Urban Rail Applications', Arnold Miller (Vehicle Projects LLC, U.S.A.) gave details of an industry-government consortium developing two prototype fuel cell hybrid locomotives for switching (shunting) and road switching. The former operate only within rail yards, while the latter are required to move short trains for short distances along running lines from one location to another. The object is to demonstrate locomotives with low pollution characteristics for use in environmentally sensitive areas such as seaports, and also to provide mobile generating grid capacity for military or civil emergencies. The project involves using two commercially available Green Goat® diesel/battery hybrid locomotives and adapting them with 250 kW Ballard PEM powerplants developed for the Citaro buses used in the CUTE project. Hydrogen pressure stores are provided by Dyneteck Industries, while BNSF Railways are providing funding, integration and testing facilities. The project is also supported by the U.S. Department of Energy and Department of

Defense. The switcher locomotive has a minimum weight of 127 tonnes, which is necessary to provide adequate traction. Since the fuel cell hybrid locomotive is lighter than the diesel equivalent, some 9 tonnes of steel ballast is required. The fuel cell, operating in parallel with the existing lead acid traction batteries, provides up to 1200 kW power for starting and acceleration, while a steady 75 kW is needed throughout the duty cycle of 10 hours, a total of 750 kWh. The first locomotive is expected to be completed within the next 6 months for evaluation.

Consumer Electronic Devices

There are rapid strides being made towards fuel cell power for consumer electronic devices such as mobile telephones and laptop computers, with most of the world's major electronic device manufacturers involved in development projects. Several systems use PEM fuel cells with hydrogen pressure vessels and hydride stores; others use direct methanol fuel cells (DMFCs). At present no technology appears to be 'head and shoulders' above the others, while several developments appear to be approaching the commercial stage. It is likely to be consumers who decide which will ultimately be successful. Considerable effort is being devoted to developing and demonstrating refuelling systems for each type of cell, as befits products available to the public.

Designing a viable alternative to advanced battery packs is a formidable challenge, as explained by Ged McLean (Angstrom Power Inc., U.S.A.). The convergence of voice, data and multimedia in handheld formats has created a demand for advanced power supplies that exceed the capabilities of lithium batteries. However, any alternative will need to be of similar size and weight to the battery, since no original equipment manufacturer will sacrifice performance. The alternative must therefore provide not only an adequate power rating, but quality of power – for example, GSM devices require 217 Hz frequency and a peak power of 4 times the continuous rating. Despite the perception that consumer devices have short lifetimes, the power source will need a 2 year life, with 1000 connect/disconnect cycles, as well as withstanding thermal cycling, and a 15,000 hour mixed duty cycle with long open circuit standby periods. In addition, the shelf life may be up to 2 years, representing the time spent in the distribution chain for products sold worldwide.

One factor in favour of fuel cells is that the fuel store is separate from the fuel cell. Recent safety recalls of high-power lithium batteries have drawn attention to the possible dangers of incorporating large reserves of power inside sealed packs. Angstrom Power have developed complete systems comprising thin film fuel cells less than 1 mm thick, with a metal hydride fuel store, DC–AC inverter etc. in one compact package. In 2005 they developed a 5 V system with 1.2 W continuous output, 2.4 W peak power, with short peaks of 4 W, and a total volume of 25 cm^3. This equates to 500 Wh l^{-1}, as compared with the 400 Wh l^{-1} of lithium-ion batteries. Angstrom Power have produced an 18 cm^3 palmtop battery power pack which will fit into the battery bay, and plan a 10 cm^3 package as a cell phone replacement. The electronics industry is working to obtain approval for the carriage of various fuels on board aircraft, and flight testing is being carried out in Canada. Thus the regulatory framework is being prepared for the roll-out of fuel cells as consumer electronic power supplies.

The Toshiba Corporation, Japan, has its own view of micro fuel cells for electric gadgets, which was presented by Fumio Ueno. Toshiba have chosen DMFCs, refuelled by means of a cartridge of pure liquid methanol which can be carried separately. High-purity methanol is specified to ensure durability. The cartridge is designed to be leakage- and child-proof and can only be discharged into the fuel cell; the intention is that one cartridge may be used to replenish several types of devices. The International Electrotechnical Commission (IEC) is drawing up an international standard for methanol cartridges which will help to make them widely available and facilitate their being carried on passenger aircraft. It will also enable several DMFC manufacturers to share refuelling cartridges.

Toshiba built a laptop which could be powered by an 18 W fuel cell for 10 hours with one filling of methanol. The fuel cell operated in parallel with a lithium battery for peak power, while the fuel cell provided a slight excess over normal demand to recharge the battery. The Toshiba DMFC (45 mm × 78 mm × 7 mm) for a mobile telephone provides 16 hours of continuous talk time.

A novel method of hydrogen generation has been demonstrated by Samsung Electro-Mechanics, Korea, explained Jae Hyuk Jang, in his talk entitled 'Development of Micro-Hydrogen Generator for Mobile Fuel Cells'. The system consists of a disposable cartridge containing an inexpensive aluminium anode and a hydrogen-evolving cathode, surrounded by water. When these two electrodes are joined together electrically, hydrogen is evolved from the cathode, and the aluminium is oxidised to hydroxide, while the rate of hydrogen evolution can be controlled by the current passed. The product hydrogen can be fed to a PEM fuel cell which powers electronic devices. The Samsung target is for a device providing 30 Wh capacity consisting of a 50 cm^3 cartridge with a 20 cm^3 fuel cell. The company is developing recycling strategies for the disposable cartridges.

Jim Balcom (PolyFuels Inc., U.S.A.) explained their reasons for optimism in developing DMFC technology. Hydrogen PEM fuel cells for automotive use have progressed from power densities of around 0.56 W cm^{-2} in 1990 to 0.77 W cm^{-2} in 2005, while at the same time, platinum loadings on the electrodes have fallen from a typical 8 mg cm^{-2} to 0.5 mg cm^{-2} in the same time period. Lithium-ion batteries for electronic devices have improved linearly in their volume energy density from about 200 to 300 Wh l^{-1} between 2004 and 2006, while energy densities from DMFCs have improved from 50 to 200 Wh l^{-1} in the same period. In terms of volume power density, PolyFuel DMFC stacks have improved from 170 W l^{-1} in 2003 to 500 W l^{-1} in 2007. The point is rapidly approaching where the fuel cell will outstrip the lithium-ion battery in performance and convenience of operation. PolyFuel is collaborating with leading notebook computer manufacturers and Johnson Matthey Fuel Cells to develop catalyst and membrane electrode assemblies, and also with a number of other organisations to produce standard fuel specifications and cartridge designs and to get them approved.

Self Powered Electronic Chips

Professor Helmut Reinecke (Institut für Microsystemtechnik (IMTEK), Germany) explained in his presentation that the integration of fuel cells onto microchips is now a possibility for applications such as verifying the history of food storage conditions. An inexpensive power supply is needed to power electronic temperature sensors and transmitters for up to 6 months during storage. Overall power demand is an average of 3 μW for this period. One way to meet this is by using hydrogen stored in palladium as fuel, with atmospheric air as oxidant. It is possible to use CMOS (complementary metal oxide semiconductor) processes to apply thin (80 μm) palladium layers to monolithic integrated chips. A layer of Nafion® proton-conducting polymer membrane is then deposited on top of this, followed by a platinised carbon layer as the cathode. Tiny fuel cells are formed, each about 4 mm × 4 mm in area, located within a small reservoir containing water. This configuration will yield 70 μW output (a power density of 438 μW cm^{-2}) with a lifetime of 180 days. The system can be charged with hydrogen by imposing a current to cause electrolysis, with an efficiency of energy stored as palladium hydride of about 65%.

Exhibition and Poster Session

One noticeable feature of the Exhibition was the number of hardware and equipment items on display, ranging from fuel cell powered vehicles, including a bus and a large motor-home incorporating an auxiliary power unit, through residential combined heat and power supplies resembling domestic gas boilers, down to tiny power sources for electronic devices. Over 800 visitors enjoyed a visit to the exhibition, in addition to the conference delegates. This provided a forum for discussions between manufacturers, suppliers and potential customers.

Over 130 high-quality posters were presented, more than two dozen of which involved PEM fuel cell catalysts and components and also direct methanol and ethanol oxidation requiring the use of pgms. Six prizes were awarded for posters of exceptional content and presentation. Two of

A fuel cell minibus exhibited by the University of Glamorgan, U.K.

these concern PEM fuel cell technology, and one improvements to DMFC performance, all of which utilise pgm catalysts.

A Comparison with the First Grove Symposium

This Tenth Grove Fuel Cell Symposium provided an opportunity to assess the progress of the fuel cell industry in the intervening 18 years since the first meeting (2). Professor Gary Acres, Honorary President of the Grove Steering Committee, and former Grove medalist, explained that the first meeting was held in 1989 to celebrate the 150th anniversary of the invention of the fuel cell by Sir William Grove, a British scientist and lawyer (5). The aim of the Symposium was to provide a forum for the appraisal of the technology, and how fuel cells might influence future energy strategy. At the time, the U.S. and Japanese governments actively supported fuel cells, although there was no equivalent support in Europe.

Professor Acres recalled that in the early meeting, the technology was dominated by PAFCs, with molten carbonate and solid oxide fuel cells still at the development stage. There was a general consensus that large power generators appeared to offer most promise, since smaller units needed as much manufacturing effort as larger devices. Even for these large generators, mass production was required to bring down prices to compete with conventional devices. It was anticipated that the superior efficiency and cleanliness of fuel cell generators would lead to the installation of 2000 MW of capacity by the year 2000. Although this particular promise has not been fulfilled, technical innovation and potential markets for small portable fuel cells and consumer electronics applications now exist that were not even dreamed of at that time. There are several new areas in which fuel cells show great potential. These range from micro and portable applications exploiting the high power density obtainable from PEM fuel cells and DMFCs, to the commercial possibilities of fuel cells for residential combined heat and power. The PEM fuel cell technology developed by General Electric, used for the first Gemini space flight, was languishing by the late 1980s, only to be transformed in terms of performance and cost for automotive applications since the first Grove Symposium. It is also interesting that PAFCs, which have had slow sales for some time, are now re-emerging as they are modified to reduce costs, capitalising on their longevity and high engineering development.

One of the major differences between the First and Tenth Symposia is that much greater emphasis is now placed on pollution control, and it is becoming increasingly expensive to adapt the internal combustion engine and large power generators to meet more stringent regulations. In addition, greater recognition is paid to energy conversion efficiency and also the capability to adapt to alternative and renewable energy sources. It is now recognised that fuel cells will have to become financially competitive with conventional generators if they are to be widely adopted. Although greater efficiency and cleanliness make a cost premium viable, this has been estimated at no more than about 15% compared to conventional generators.

Conclusion

It is evident that fuel cells are already being established on a commercially viable basis in many niche markets, including military and standby power supplies. Fuel cells are gradually being accepted for other applications. There were several references at the Symposium to the 'valley of death' which represents a barrier to new products. Until devices are mass produced, their unit cost remains high, but until costs reduce, sales volumes remain limited. It is hoped that in several sectors, the numbers of fuel cells currently being manufactured and evaluated are enabling this barrier to be crossed to launch successful products commercially. The pgm costs quoted by NedStack indicate that with recycling, platinum catalysts do not constitute a significant proportion of the aggressive U.S.\$30 kW^{-1} target quoted by the U.S. Department of Energy for PEM fuel cells in 2015 (4). Platinum catalysts are likely to continue to dominate the low-temperature fuel cell market in view of their superior performance.

The Eleventh Grove Fuel Cell Symposium is scheduled for September or October 2009 in London. Technical developments in the fuel cell field will be reported in Fuel Cells Science and Technology 2008, which will be held on the 8th and 9th October 2008 at the Danish Confederation of Industry Conference Centre, Copenhagen, Denmark (6).

References

1 The Grove Fuel Cell Symposium: http://www.grovefuelcell.com/

2 Platinum Metals Review: Nuggets, Fuel Cells: http://www.platinummetalsreview.com/dynamic/booklist#fuelcells

3 Auto Industry, World Vehicle Production Since 1997 by Region: http://www.autoindustry.co.uk/statistics/production/world

4 N. Garland, 'U.S. Department of Energy Fuel Cell Sub-Program', Fuel Cell Seminar, Presentations, San Antonio, Texas, 16th–19th October, 2007: http://www.fuelcellseminar.com/2007_seminar.asp

5 J. Wilson, W. Wilson and J. M. Wilson, "William Robert Grove. The Lawyer Who Invented the Fuel Cell", Metolius Ltd., Hereford, U.K., 2007

6 Fuel Cells Science and Technology 2008: http://www.fuelcelladvances.com/

Delegates to the Grove Symposium were able to enjoy spectacular panoramic views of central London and Westminster from the windows of the Queen Elizabeth II Conference Centre

The Reviewer

Don Cameron is an independent consultant on the technology of fuel cells and electrolysers. As well as scientific aspects, his interests include the standardisation and commercialisation of these systems. He is Secretary of the Grove Symposium Steering Committee.